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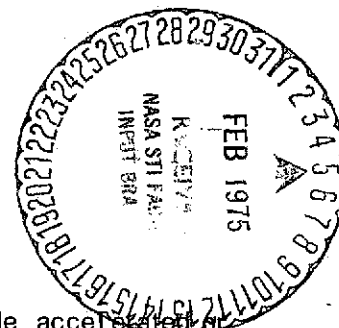
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**PRELIMINARY FLIGHT TESTS OF AN OCULOMETER**

By D. B. Middleton, G. J. Hurt, Jr., M. A. Wise and J. D. Holt

November 1974



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# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## PRELIMINARY FLIGHT TESTS OF AN OCULOMETER

By D. B. Middleton, G. J. Hurt, Jr., M. A. Wise and J. D. Holt

### SUMMARY

A remote-sensing oculometer has been successfully operated during flight tests with a DHC-6 Twin Otter aircraft at the Langley Research Center. Even though this device was designed primarily for the laboratory, these tests demonstrated that it was able to track the pilot's eye-point-of-regard (lookpoint) consistently and unobtrusively in the flight environment. Specifically, it was demonstrated that (1) the oculometer equipment will operate effectively in the presence of appreciable vibration, and that (2) the instrument being monitored at any time can be instantly determined. The instantaneous position of the lookpoint was determined to within approximately 1 degree.

Data were recorded on both analog and video tape. Not enough test runs were made during the flight program to support a general statistical analysis, but enough data were obtained to indicate a general scan pattern and the most frequently monitored information during ILS landing approaches under simulated IFR conditions. The video data consisted of continuous scenes of the aircraft's instrument display and a superimposed white dot (simulating the lookpoint) dwelling or moving from instrument to instrument as the pilot monitored the display information during the landing approaches. These video tapes may be viewed at the Flight Dynamics and Control Division, Langley Research Center.

### INTRODUCTION

At the Langley Research Center a nonintrusive, eye-measuring device called an oculometer has been used to measure a pilot's look direction and determine his associated lookpoint during ILS landing approaches. Lookpoint is defined herein as the point where the pilot's instantaneous line of sight intersects the instrument panel.

The oculometer was developed for Langley by Honeywell Radiation Center of Lexington, Massachusetts. Several prototype oculometer configurations have been built and tested under laboratory conditions (ref. 1-5). One configuration requires that the translational movements of the pilot's eye be restricted to a 1 cubic inch volume. This configuration has been tested in a moving-base simulator at Langley (see ref. 6). A later version permits freedom of eye movement within a volume of approximately 1 cubic foot; this system is also described in reference 6. As a result of the laboratory and simulator testing it was concluded that an oculometer will not distract a pilot from his normal routine and will provide useful and valid eye data.

Flight tests have been made with the 1-cubic-inch configuration to: (1) ascertain if this conclusion remained valid in an actual IFR landing approach situation and (2) determine if the oculometer equipment would operate effectively in a typical flight environment. Although unplanned, part of the flight tests took place in considerable turbulence due to the onset of a late-evening thunderstorm. The results of the flight tests are reported herein.

## SYMBOLS AND DEFINITIONS

In order to facilitate international usage of the data presented, dimensional quantities are presented in both the International System of Units (SI) and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

$a_o$	constant in the x-linearization equation (equation 1)
$a_i$	coefficients in equation 1 ( $i = 1, 2, 3, 4$ )
$b_o$	constant in the y-linearization equation (equation 2)
$b_i$	coefficients in equation 2 ( $i = 1, 2, 3, 4$ )
$x$	transverse component of the eye's lookpoint with respect to an established "null point" in the plane of the instrument panel
$x_c$	corrected x-value (see equation 1)
$x_{TV}$	the position along a TV raster line as determined by a digital counter (reset to zero at the beginning of each raster line)
$y$	vertical component of the eye's lookpoint with respect to an established "null point" in the plane of the instrument panel
$y_c$	corrected y-value (see equation 2)
$y_n$	typical raster scan line (see figure 6)
$y_{TV}$	TV raster line number as determined by a digital counter (reset at the beginning of each field)

### Axis Systems

$x, y$	orthogonal coordinates of the subject's lookpoint with the origin at the established null point
$x_{TV}, y_{TV}$	digital coordinate system with the origin at the top left corner of the monitor displaying the video signal from the electro-optical sensor unit

## Abbreviations

IFR	Instrument Flight Rules
ILS	Instrument Landing System
IR	Infrared
MM	Middle Marker
OM	Outer Marker
RMI	Remote Magnetic Indicator
rpm	revolutions per minute
TV	television
V	Volts
VDC	Volts of Direct Current
$\mu\text{m}$	micro-meters (meters $\times 10^{-6}$ )

## DESCRIPTION OF OCULOMETER SYSTEM

The primary function of the oculometer is to measure the look-direction of a subject's eye without interfering with his assigned activities. Secondary information such as pupil diameter and blink rate can also be obtained. The principal application during the flight tests was to indicate continuously which instrument the pilot was observing during ILS landing approaches under simulated IFR conditions.

The basic oculometer system consists of a sensing subsystem (electro-optical) and video-signal processor. Additional electronics and optics were added during the flight tests to aid the oculometer operator and to combine the eye data with a closed circuit television view of the pilot's instrument panel. These components are described in the following sections.

### Sensing Subsystems

The function of the sensing subsystem is to provide special illumination for the subject's eye and to obtain continuous information about its orientation (i.e., where it is looking). A near-infrared (IR) illumination source and an IR-sensitive television (TV) camera were used in combination to obtain a video signal containing pertinent details of the eye. At the near-IR wavelengths (0.8 to 0.9  $\mu\text{m}$  bandwidth) the eye has optical characteristics (reflective and refractive) similar to those it has for visible light (see ref. 1), yet relatively high levels of such illumination cause no physical discomfort to the eye and do not cause the diameter of the pupil to decrease appreciably.

(If pupil diameter contracts to less than 3 millimeters the eye cannot be tracked with the oculometer.)

The subsystem is housed in a single unit which contains the illumination source, the TV camera, and suitable illumination and collection optics. Figure 1 is a photograph of the sensing unit with its covers removed. A schematic diagram of the arrangement of the components in this unit is shown in figure 2. A 100 watt tungsten lamp is the illumination source and filters in the optical path restrict the transmitted light to the abovementioned bandwidth. Lenses L3 and L4 then collimate the near-invisible light into a circular beam which appears to the subject as a dull red glow and does not interfere with his normal vision. In fact, the subject is usually unaware of this light unless he looks directly at the fixed mirror where he sees a "round red disc." The cross-sectional area of uniform intensity of the IR beam is approximately 1 square inch at the pilot's eye. The image of the eye will remain in focus for a translational depth of approximately 1 inch along the optical path. Thus, an effective volume of 1 cubic inch is defined as the operational "eyespace" for this oculometer. This eyespace volume is a compromise providing sufficient resolution at the sensor while at the same time allowing slight head movements. A beam splitter (see figure 2) is used to combine the illumination and collection optical paths. Thus, when the eye is located within the illumination beam, its enhanced image is focused onto the face of the vidicon tube in the camera.

The television camera in the sensing unit is a self-contained, 525 line rate camera modified to accommodate a silicon-matrix vidicon tube. The silicon-matrix tube is the heart of the oculometer sensing unit, and because of its ruggedness and its efficiency in the IR region, it is superior to sensing tubes used in previous oculometers (ref. 3). An additional advantage of this camera is its inherent compatibility with readily available closed-circuit TV monitors, recorders, and signal-conditioning equipment.

The basis of the oculometer data is the output video signal from the TV camera in the sensing unit. During the flight tests this signal was (1) recorded directly for postflight analysis, (2) used as the data input to a signal processor, and (3) displayed on a TV monitor. The displayed signal appeared as a bright disc (pupil) with a superimposed small bright spot (reflection of light-source) as shown in figure 3. By displaying the signal on this monitor the oculometer operator could visually determine where the pilot's eye was within the eyespace. When the pilot's eye was not approximately centered, the operator could instruct the pilot, by way of the intercom, which way to move his head to return his eye to the center of the eyespace. Very few corrections, however, were required during the flight tests.

Principle of Operation.- When the subject's eye is within the eyespace, it is illuminated uniformly by the IR beam. Part of the rays enter the eye through the pupil and part are reflected by the cornea. The rays entering the eye are reflected from the retina, effectively backlighting the pupil so its image appears as a bright disc on the TV tube. On the other hand, the rays reflected

by the cornea produce a virtual image of the illumination source located halfway between the vertex and the center of curvature of the cornea. The image appears as a small bright spot (hereinafter called "corneal reflection") as illustrated in figure 4. The figure also shows the relative position of the corneal reflection with respect to the pupil for several typical eye positions.

The basic measurement made by the oculometer is the displacement of the corneal reflection relative to the center of the pupil. All of the information required for this measurement is contained in the video signal from the sensing unit. By adjusting the blanking level of the TV camera all eye details except the "bright pupil" and the corneal reflection can be eliminated from the video signal (see figure 3). Low contrast areas such as facial skin, iris, and sclera (white of the eye) are thus blanked out and the corneal reflection appears brighter than the pupil. The video signal goes to a signal processor which makes the above-mentioned measurement.

### Video Signal Processor

The signal processor consists of a commercial standard minicomputer with two specialized interface circuit boards. A photograph of this unit is shown in figure 5. The minicomputer has a memory capability of 16,000 sixteen-bit words. A teletype keyboard with a paper tape punch and reader is used to load the oculometer program into memory and to communicate with the minicomputer. The teletype unit is not necessary for operation of the oculometer after initial setup. (It was not carried onboard the aircraft during the flight tests.)

The top part of figure 6 is an enlargement of the eye detail from figure 3. The horizontal line  $y_n$  is a typical raster line which intersects both the pupil and the corneal reflection. Below the photo is shown a signal which is proportional to the light intensity along  $y_n$ . The abrupt changes in signal level occur at the edges of the pupil and the corneal-reflection images (i.e., at "boundary points" A, B, C, and D). The boundary points are detected in the interface section of the signal processor by comparing the light level with fixed threshold levels.

The coordinates ( $x_{TV}$ ,  $y_{TV}$ ) of the boundary points for every raster line intersecting the pupil and/or corneal-reflection images are determined by the interface section. The  $y_{TV}$  coordinate is simply the TV scan line number obtained from a counter which is reset to zero at the beginning of each field. The  $x_{TV}$  coordinate for each point is obtained from a second counter which is started at the beginning of each scan line. (The x-counter measures position along the raster line as a function of time.) The coordinates are then converted to 10-bit digital words which are written into the memory of the minicomputer.

The primary task of the minicomputer program was to analyze all of the boundary points and then to determine the  $x_{TV}$ ,  $y_{TV}$  coordinates of the center of the pupil and the center of the corneal reflection, their relative displacement and the diameter of the pupil. (Pupil diameter was recorded but not analyzed in this study.)

The signal processor had four output channels. Three were analog signals with a range of  $\pm 5$  VDC, and the fourth was a logic voltage (track/no-track signal) telling whether the eye was in or out of track. One of the analog channels output a voltage proportional to the pupil diameter and the other two gave voltages proportional to the x and y components of the subject's lookpoint on the instrument panel. This lookpoint was a function of the azimuth and elevation angle of the subject's instantaneous line of sight with respect to a selected zero reference point (referred to hereinafter as "null point") on the instrument panel. The azimuth and elevation angles were in turn proportional to the measured relative displacement of corneal reflection and the center of the pupil. The four output signals were recorded on an onboard aircraft instrumentation recorder. Three of them were also used for inputs to a scan converter.

### Additional Electronics and Optics

The scan converter has the unique capability of combining a video signal with a pair of analog signals. In the present application the result was a video scene with a superimposed electronic dot which could move with respect to the video scene. The dot was synthesized from the x and y components of the lookpoint. The scan converter and a second TV camera were used in the present study to generate an annotated TV scene, consisting of the simulated lookpoint (viz., the dot) superimposed on a video scene of the instrument panel.

The scan converter also has provisions for a blanking input signal and a memory feature. The blanking feature allows the electronic dot to be eliminated from the scene under certain conditions. For example, when the track/no-track signal from the signal processor was used as the blanking input, the operator (watching a TV monitor) was able to tell that the pilot's eye was not being tracked when the dot disappeared from the annotated scene. (Without such a blanking feature the operator might think that the subject was staring at one spot on the instrument panel when, in fact, the eye was out of track.) The memory feature on the scan converter is similar to that of a storage oscilloscope (or "Memoscope"). When in the "storage mode," the dot traced out the pilot's scan pattern as shown by the example on the monitor in figure 7. The oculometer operator could erase the pattern as often as desired.

The only output from the scan converter was the annotated video signal which was recorded on video tape. With the memory feature inactive the recording showed the dot moving from instrument to instrument as the pilot scanned the instrument panel. However, with the memory feature active scan patterns such as shown in figure 7 could be recorded as they were being generated.

### Calibration and Linearization

Accessory routines in the minicomputer program provided semi-automatic procedures for the calibration and linearization of the output signals. These procedures had to be performed for each pilot because of differences in their eye characteristics. In fact, the output signals for the left and right eye of a given subject may be significantly different because of a difference in eye geometry.



The calibration process involved the pilot fixating in turn on three selected points on the instrument panel. A point on the instrument panel was selected as the null point which became the origin of the x,y axis system. This point was at the approximate center of the turn and slip indicator. This selection, although arbitrary, was convenient to establish a null point which was close to the optical path between the eye and the sensing unit. Next, an x-calibration point was selected about 20 degrees to the right (or left) of the null point and a y-calibration point was established about 20 degrees above the null point. For convenience, these two points were located on the x and y axes, respectively. The coordinates of all three points were entered into the memory of the minicomputer along with a desired output voltage for each. Next, the minicomputer was placed in the "calibration mode" and the pilot was instructed to fixate on each of the three points. At each fixation the operator pressed a switch to capture a digital number related to the distance between the corneal reflection and the center of the pupil. The minicomputer then automatically adjusted the x and y output voltages to the assigned values thus establishing the calibration.

The linearization process is used to remove distortions from the output data caused by equipment anomalies and subject-to-subject eye variations. The relationship between the position of the corneal reflection relative to the pupil center and eye direction is approximately linear for look angles up to 10 or 20 degrees away from the reference line of sight. However, significant nonlinearities exist at 30 degrees. These nonlinearities are due, in part, to the way in which the position of the center of the pupil is determined and, in part, to the geometry of the eyeball and test setup.

Nonlinearities are corrected in the oculometer by means of polynomial equations which introduce equal and opposite nonlinearities. The following polynomials were used for linearization in this study.

$$x_c = a_0 + a_1x + a_2xy + a_3xy^2 + a_4y \quad (1)$$

$$y_c = b_0 + b_1y + b_2(y^2 - x^2) + b_3yx^2 + b_4x \quad (2)$$

where  $x_c$  and  $y_c$  are the corrected values for the lookpoints and the terms on the right were developed empirically according to the types of distortion noted in oculometer measurements using test arrays. (A nominal array is shown in figure 8.) Examples of distortion patterns and associated linearizing terms are shown in Table I.

The coefficients of these polynomials are chosen by the minicomputer to yield the minimum rms error over the array of fixation test points. To utilize this feature the subject looks at each test point in figure 8 and its fixation value is stored in the minicomputer memory by the operator moving a switch (A typical set of measured fixation values is shown in figure 9.) After all of the test-point fixations have been stored, the computer automatically adjusts the linearizing coefficients to achieve a minimum rms error (figure 10).

The linearizing coefficients for up to nine subjects can be stored in the mini-computer memory.

## SYSTEM PERFORMANCE

The present tracking range of the oculometer covers a viewing field of  $\pm 30$  degrees in azimuth and  $-10$  degrees to  $+30$  degrees vertically (referenced to the pilot's line-of-sight to the fixed mirror). Laboratory tests have indicated (ref. 5) that the average error in tracking subject's eyes within this field is less than 1 degree. The average error in tracking the pilot's eye during the present flight tests was determined to be  $1.02^\circ$  over the field spanned by the 17 test points used for the linearization process. However, the average error for 11 of these points that cover only the flight-instrument area (excluding the clock) is  $0.93^\circ$  (the largest errors were on the left side of the panel beyond the instrument area). A  $1^\circ$  error corresponds to approximately a 1.27 cm (one-half inch) lookpoint error.

## DESCRIPTION OF TEST AIRCRAFT

The airplane used for this test was a DHC-6 de Havilland Twin Otter which is a fixed gear, high-wing monoplane powered by two single stage, free-power turbine engines. It is shown in figure 11. The Twin Otter is a passenger/cargo type which carries a crew of pilot and copilot and up to 19 passengers. The airplane has a wing span of 19.81m (65 ft) and a fuselage length of 15.77m (51.75 ft). The maximum takeoff weight is 5252.23 kilograms (11,579 lbs) and the maximum landing weight is 5171.04 kilograms (11,400 lbs). Takeoff speed is approximately 65 knots, normal cruise 130 to 150 knots, and the landing approach speed is approximately 90 knots.

## Oculometer Installation

Equipment constraints dictated that the copilot side of the cockpit be used for these tests. The flight instruments on the copilot's panel consisted of the nine instruments shown in figure 12.

Installation of the oculometer components in the DHC-6 de Havilland Twin Otter did not require any major modification of the airplane or functional changes to the oculometer itself. The sensing unit of the oculometer was secured to the floor between the copilot seat and the rudder pedestal post (see figure 13). The unit as installed did not interfere physically with the copilot or his attitude control system. The fixed mirror was attached to the sensing unit rather than the instrument panel in order to minimize vibration differences between the sensing-unit illumination source and the mirror. A headrest (two pads shown above the copilot seat) served as a physical point of reference for

the pilot rather than a head restraint. By maintaining an approximate head contact with the headrest, the pilot's eye would be in or very near the designated eyespace. A television camera was mounted in the cockpit doorway to provide a view of the instrument panel. This camera view (i.e., video signal) was used as an input to the scan converter for the composite scene as shown in figure 7. The instrument panel as seen from the approximate location of this television camera is shown in figure 14.

The remainder of the oculometer and television equipment required for the flight tests was located in the passenger compartment as shown in figure 15. The components were fastened to a shock mounted pallet which was attached to the hold-down points normally used for the passenger seats. The components consisted of two 9-inch television monitors, a camera control unit for the television camera mounted in the doorway, a scan converter, the signal processing unit, associated electronics, and a video tape recorder. The oculometer operator's seat was located immediately to the rear of the video tape recorder and facing the 9-inch TV monitors. From this position he could monitor the pilot's eye position relative to the designated eyespace.

A 110V, 60 cycle rotary inverter (driven by one of the airplane's 100 ampere D.C. generator) was added to supply power for the oculometer components. The inverter was located in the rear section of the airplane. The total equipment weight (oculometer, cameras, recorders, and inverter) added to the aircraft for these tests was approximately 145.15 kilograms (320 lbs).

The Twin Otter was a convenient choice for the oculometer flight test because it already contained instrumentation to sense and record a variety of flight parameters. The oculometer signals were recorded on this system along with the flight parameters. Thus, the pilot's eye position data can be correlated with the airplane situation and control data. The instrumentation is shown in the lower right corner of figure 15.

## TESTS AND RESULTS

The oculometer flight tests were made primarily to demonstrate that the oculometer equipment would operate consistently and accurately under actual flight conditions (or alternately to identify any unexpected problems which preclude present use of such equipment in flight). A secondary objective was to obtain eye-point-of-regard data as the pilot shifted his attention from instrument to instrument during ILS landing approach. Both objectives were accomplished, even though the flight program was abbreviated and only a limited amount of data was obtained.

Prior to the data flights the aircraft's engines were run up to maximum rpm on the flight line to produce a severe vibrational environment (much more severe than subsequently experienced in the flight tests). A subject's eye was tracked successfully during this exercise, although there was a noticeable jitter in the video output signal from the electro-optical sensor unit. (This was caused partly by equipment vibration predominately in the y-axis of the fixed mirror,

and partly by vibrations of the subject's head with respect to the sensing unit. The amplitude of the jitter was estimated to be a maximum of 0.5 degree peak to peak in the output signal of the signal processor. Next, a successful shakedown flight was made to verify operation of the equipment in flight and especially during the touchdown.

Two data flights were made. These consisted of a series of nighttime ILS landing approaches at Langley Air Force Base under simulated IFR conditions. Five of these approaches provided usable data. A profile of a typical approach at Langley is shown in figure 16.

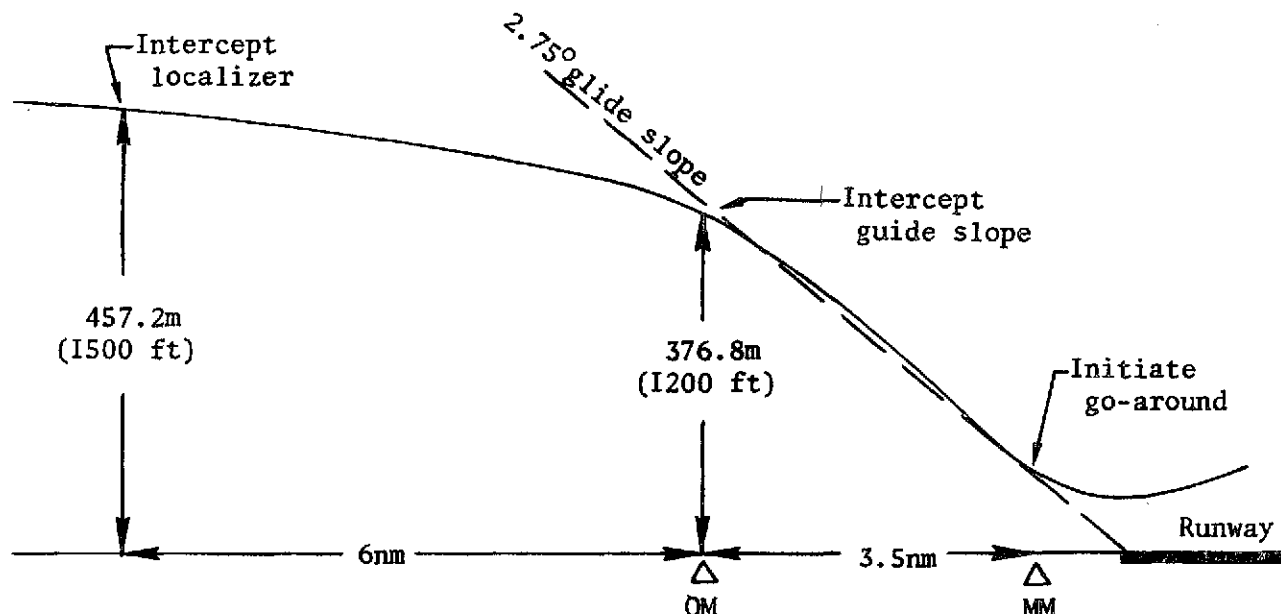


Figure 16.- Sketch of typical ILS landing approach profile.

Two pilots were used on each data flight. A "safety pilot" flew the landing patterns and maneuvered the aircraft into the vicinity of the localizer about 10 nautical miles out. Here the "oculometer pilot" assumed control; he acquired the localizer and set up a slow descent to the outer marker (OM) where he acquired the 2.75 degree glide slope and continued to the middle marker (MM). The aircraft reached the 61 meter (200 feet) altitude minimum near the middle marker where the safety pilot reassumed control and executed a go-around.

In general, data were recorded only during the profile segment from OM to MM. Oculometer signals were recorded on both video tape and on the test aircraft's special onboard instrumentation recorder (see figure 15). The signals recorded on this magnetic tape system were the four outputs from the oculometer's signal processor unit (see figure 5). A number of aircraft parameters were also simultaneously recorded on the magnetic tape for correlation to the oculometer data. Two types of video recordings were made: (1) "raw" video signal from the oculometer's electro-optical unit and (2) a video composite consisting of

the synthesized x and y components (viz., an "electronic dot") of the pilot's look-direction superimposed on a live view of his instrument panel obtained from a second TV camera. Thus, a viewer of the composite picture can watch the "dot" travel from instrument to instrument as it traces out the pilot's scan pattern in real-time. The viewer can also follow the progress of the ILS approach by monitoring the aircraft instruments and listening to the voice channel which was tied into the aircraft's intercom system.

After taking a preliminary look at the magnetic tape data (played back on a strip chart recorder) and reviewing the video tapes, it was apparent that the oculometer had tracked the pilot's eye satisfactorily and that data were successfully recorded. The pilot stated that the cockpit components of the oculometer did not interfere with the flight situation. The jitter in the oculometer output signals was more than had been experienced in the laboratory but less than the 0.5 degree amplitude observed in the system checkout during ground run-up of the airplane engines. This caused no problem in determination of the particular instrument being monitored at any given time. The instantaneous lookpoint on the face of an instrument was determined to within approximately 1 degree or about 1.27 centimeters (0.5 inch).

Next, the x and y output signals were analyzed to obtain dwell times on and transitions among the six most used flight instruments during the landing approaches. Results for the first approach of the test series on the second flight are shown in Table II. The instrument names appear in the same order in the row and column headings; thus, each name intersects itself along the table diagonal. Data entries along this diagonal are percents of total tracking time (157 seconds) spent observing the respective instruments. Off-diagonal entries are the number of one-way transitions between the various instruments. Mean dwell times per observation (and standard deviation) for each instrument are listed at the bottom of the appropriate column.

The data show that over two-thirds of the time was spent monitoring the "ILS" instrument and each observation was usually longer than one second. Only a modest amount of time (3 to 5 percent) was spent monitoring airspeed, attitude, and altitude, and very little time was spent on the RMI and VSI. Total time on instruments adds up to approximately 82 percent; the remaining 18 percent involves transition time between instruments or time glancing at switches and the safety pilot. This same general trend held for subsequent approaches although the percentages varied somewhat.

The number of transitions between any two instruments is determined from Table II as follows: Select the "from" instrument from the row headings and follow this row across to the column of the desired "to" instrument; the number of one-way transitions is listed at the intersection. The number of transitions in the opposite direction is obtained by interchanging the labels of the "to" and "from" instruments and repeating the process. For example, the number of transitions from the ILS to the altimeter is listed as 7 and the number of returns was 14.

Although the pilot was not used to flying simulated IFR approaches in this aircraft (especially from the right-hand seat), this had no effect on accomplishment of the primary objective of the mission. However, because the copilot's instruments (see fig. 12) were used, the data values in Table II should not be considered typical of a pilot's scan pattern while flying IFR approaches in a Twin Otter. (The copilot's panel in the test airplane had the required instruments for making an ILS approach. However, they were not arranged as normally would be found on the pilot's panel of a Twin Otter.) The values do, however, generally agree with those obtained on the simulator for other aircraft (e.g., see ref. 5), and thus, offer further evidence that the oculometer and all recording equipment were functioning satisfactorily during the flight tests.

#### CONCLUDING REMARKS

An oculometer has been successfully operated during flight tests with a DHC-6 Twin Otter aircraft at the Langley Research Center. Even though this device was built for laboratory testing it was able to track the pilot's eye-point-of-regard (lookpoint) consistently and unobtrusively in the flight environment. Specifically, it was demonstrated that (1) the equipment will operate effectively in the presence of appreciable vibration and the (2) the instrument being monitored at any instant can be easily identified. Also, the instantaneous lookpoint on the face of an instrument was determined to within approximately 1 degree or about 1.27 centimeters (1/2 inch).

Not enough test runs were made during the flight program to support a general statistical analysis, but enough data were obtained to indicate scan patterns and the most frequently monitored information. These data were in general agreement with values obtained with the oculometer during a similar piloting task on a simulator. This agreement thus provides further evidence that the oculometer and all recording equipment were functioning properly under the flight conditions encountered.

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Table I. - Examples of the distortion patterns and the associated linearizing terms.

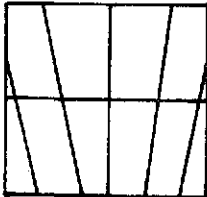
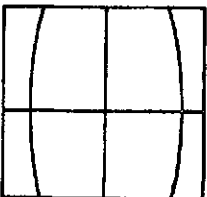
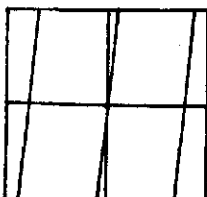
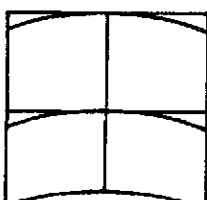
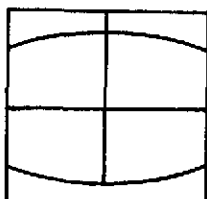
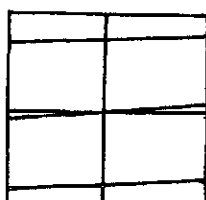
Distortion pattern	Linearization term
	$XY$
	$XY^2$
	$Y$
	$Y^2 - X^2$
	$YX^2$
	$X$



TABLE II

PATTERN OF MONITORING INSTRUMENTS DURING INITIAL LANDING APPROACH IN A DHC-6 TWIN OTTER

TO -

Instrument	ILS	Airspeed	Attitude	Altimeter	RMI	VSI
ILS	68.44%	16	9	7	1	0
Airspeed	9	5.32%	8	1	1	0
Att. Ind.	8	2	3.32%	9	1	0
Altimeter	14	0	2	3.19%	0	1
RMI	1	1	0	0	1.03%	1
VSI	1	0	1	0	0	0.25%
Mean Dwell Time, sec	1.801	0.179	0.110	0.283	0.587	0.025
Standard Deviation, sec	2.611	0.280	0.176	0.330	0.832	0.000

FROM -



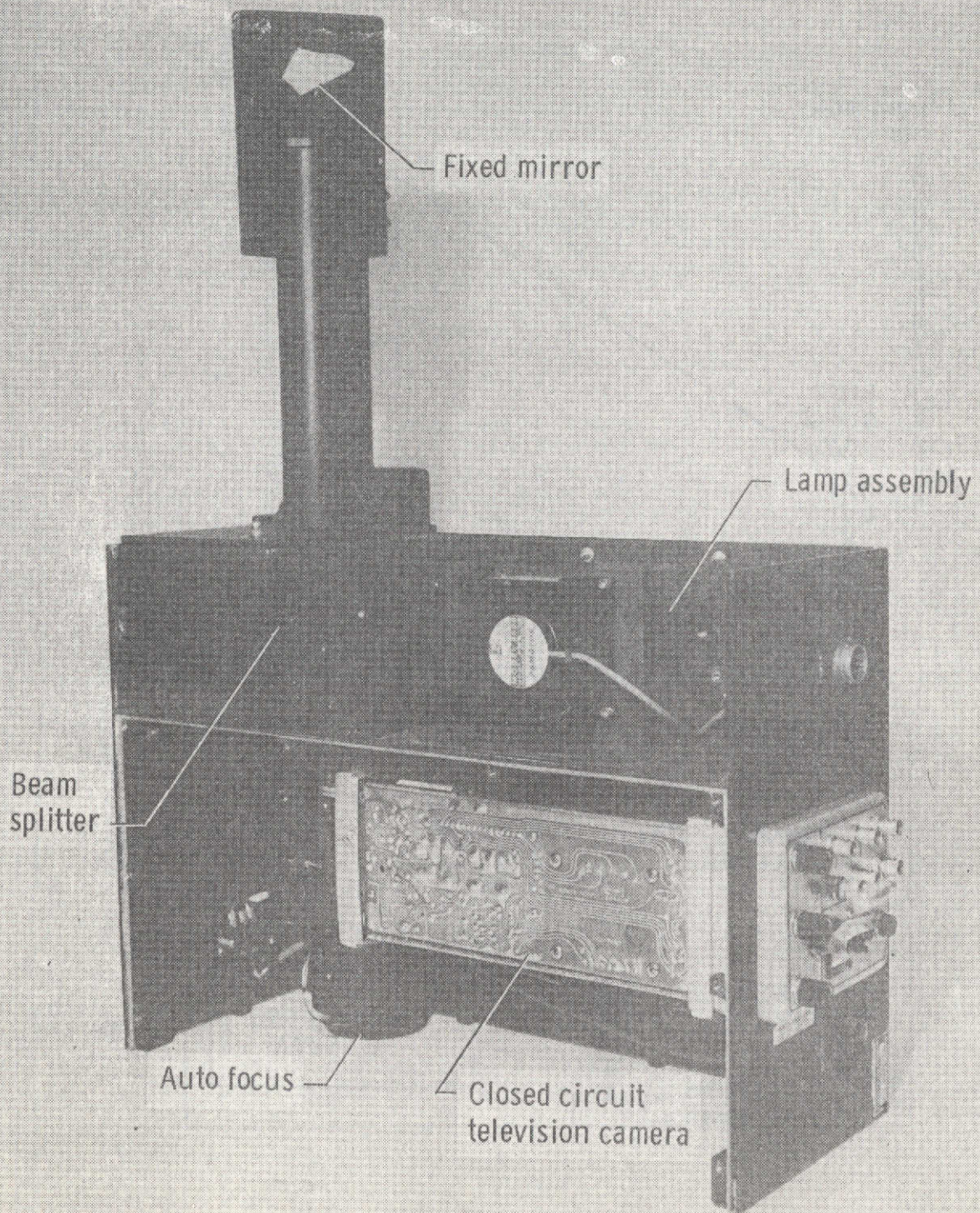


Figure 1. - The electro optical sensing unit with covers removed.

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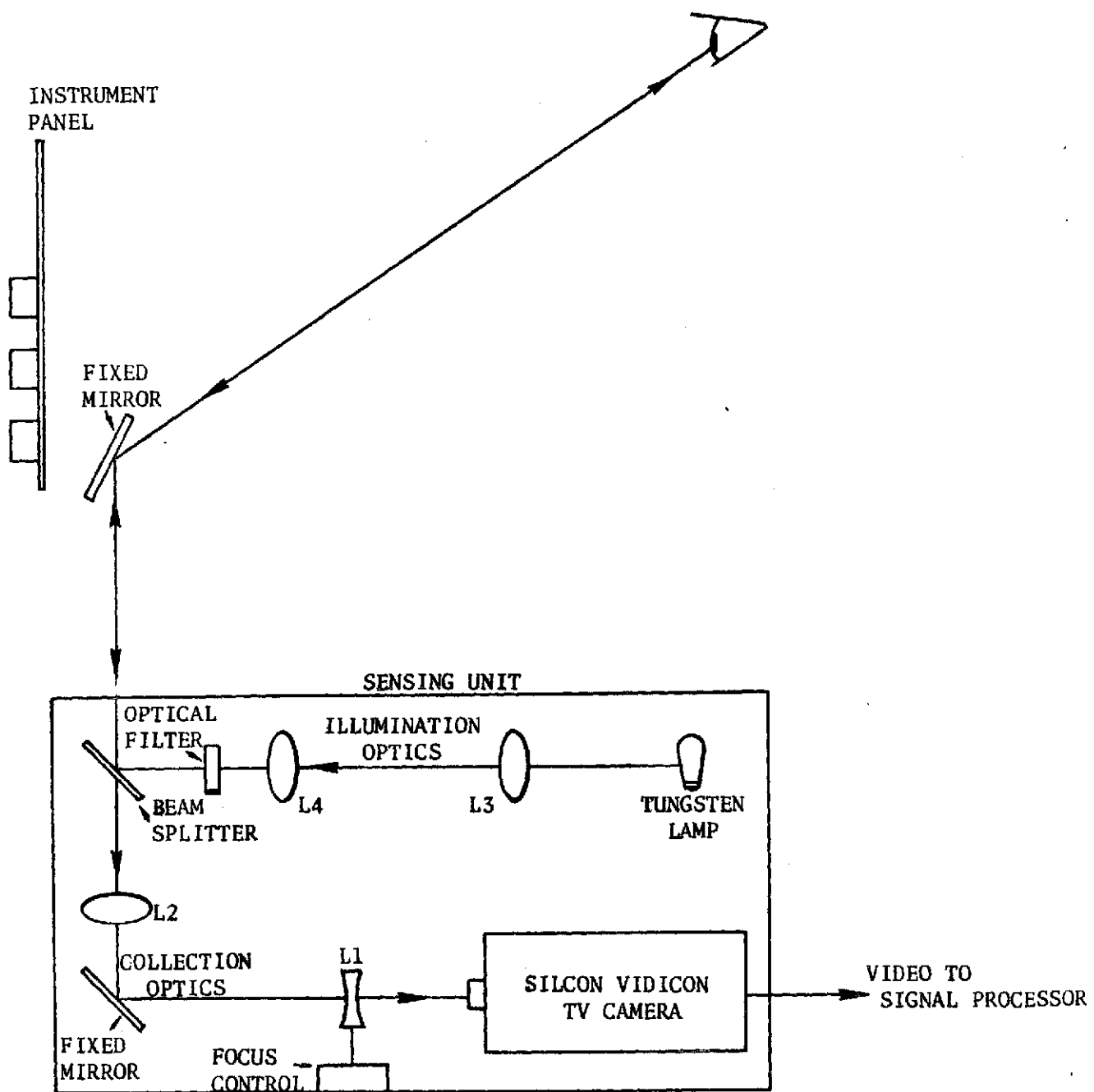


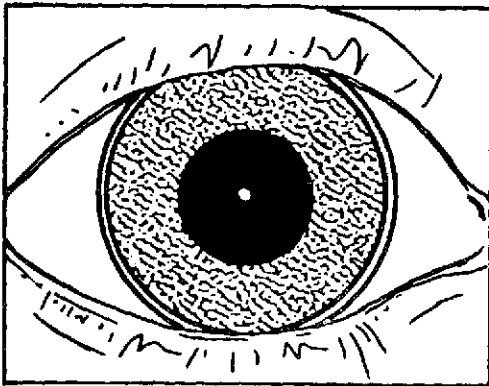
Figure 2.- Schematic diagram showing sensing unit components.

Large circle - "back lighted" pupil  
Bright spot - corneal reflection

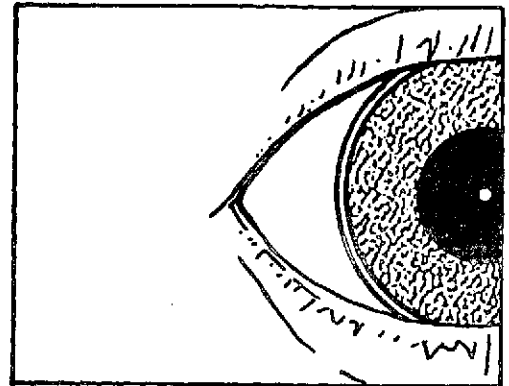


Figure 3. - TV monitor display of video signal from sensing unit.

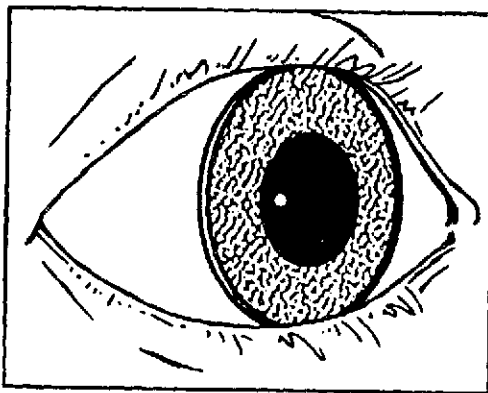
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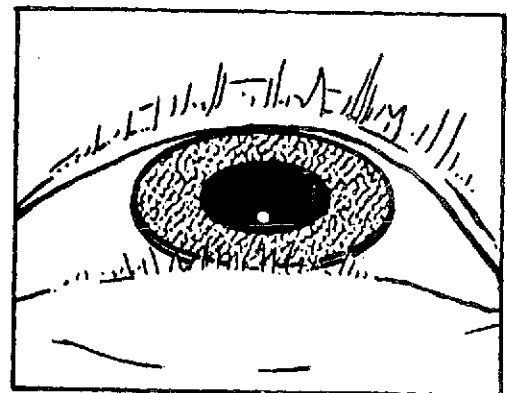
(a)



(b)



(c)



(d)

- (a) Eye looking straight ahead (at illumination source) - note corneal reflection is at center of pupil.
- (b) Eye looking straight ahead but laterally displaced - note corneal reflection still at center of pupil.
- (c) Eye looking to the side - corneal reflection displaced horizontally from pupil center.
- (d) Eye looking up - corneal reflection displaced vertically from the pupil center.

**Figure 4. - Relative locations of pupil and corneal reflections for several eye orientations.**



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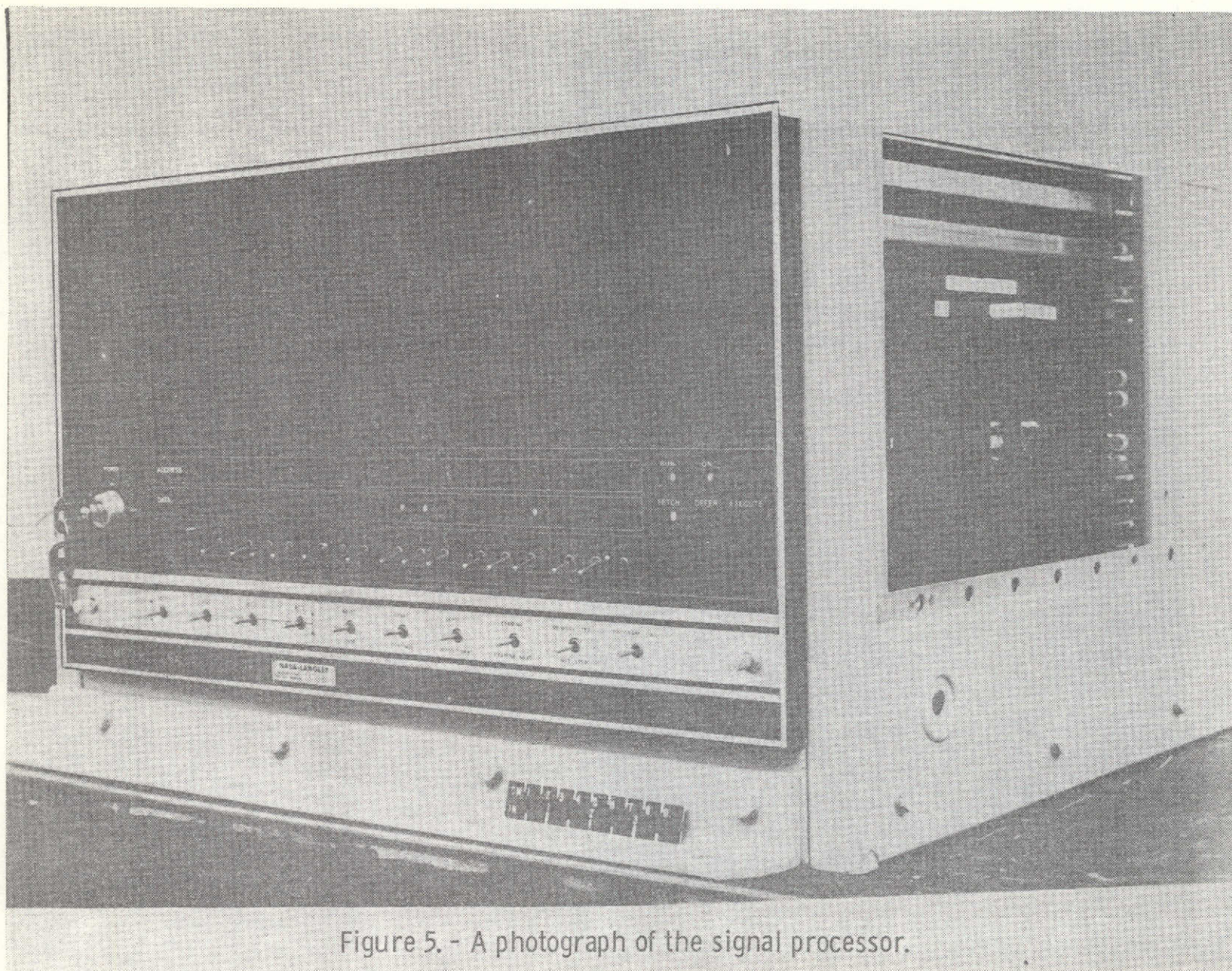


Figure 5. - A photograph of the signal processor.



A, B, C, and D are contrast boundary points

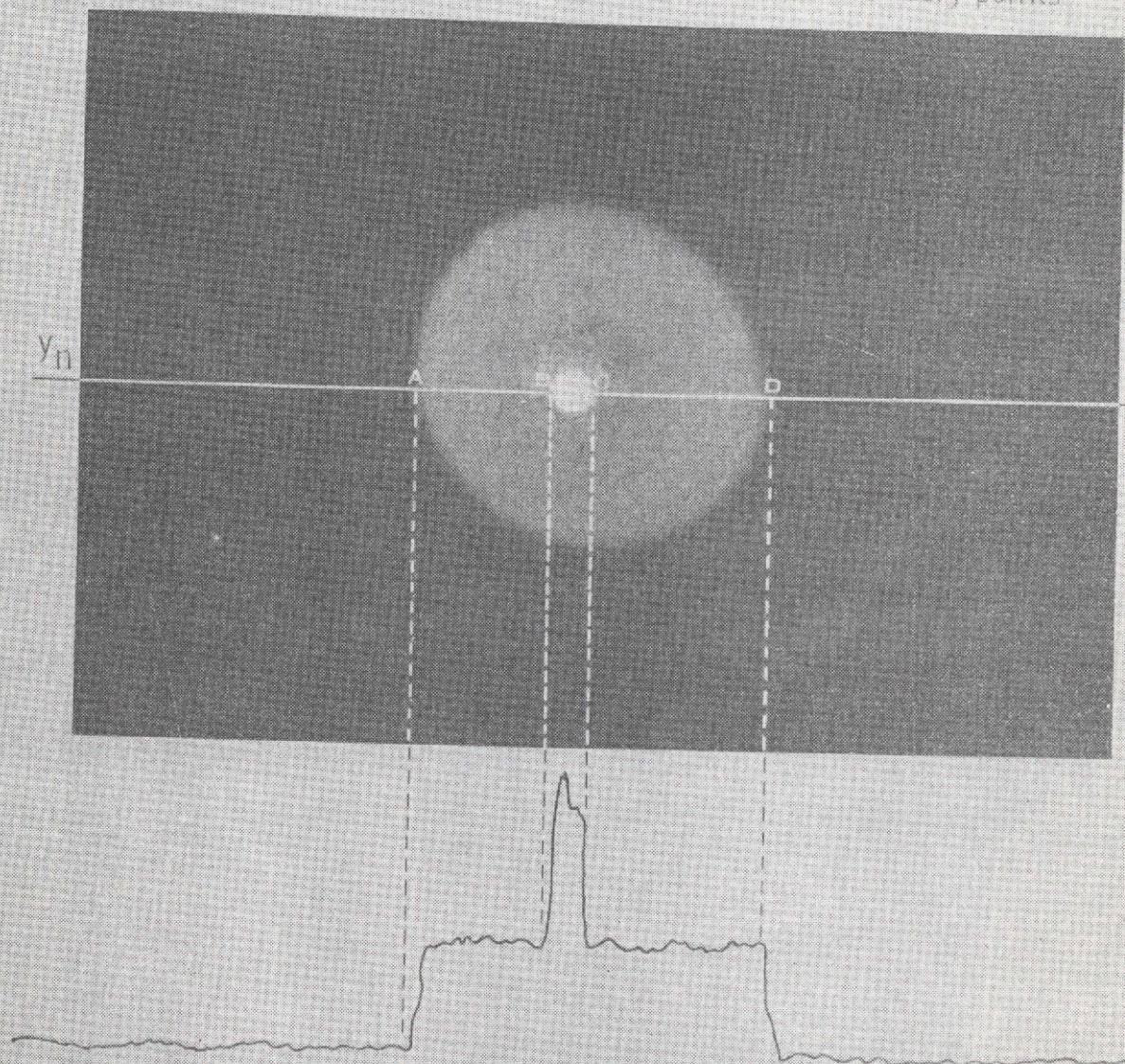


Figure 6. - Light intensity analysis of a typical raster line  $y_n$  by the signal processor.



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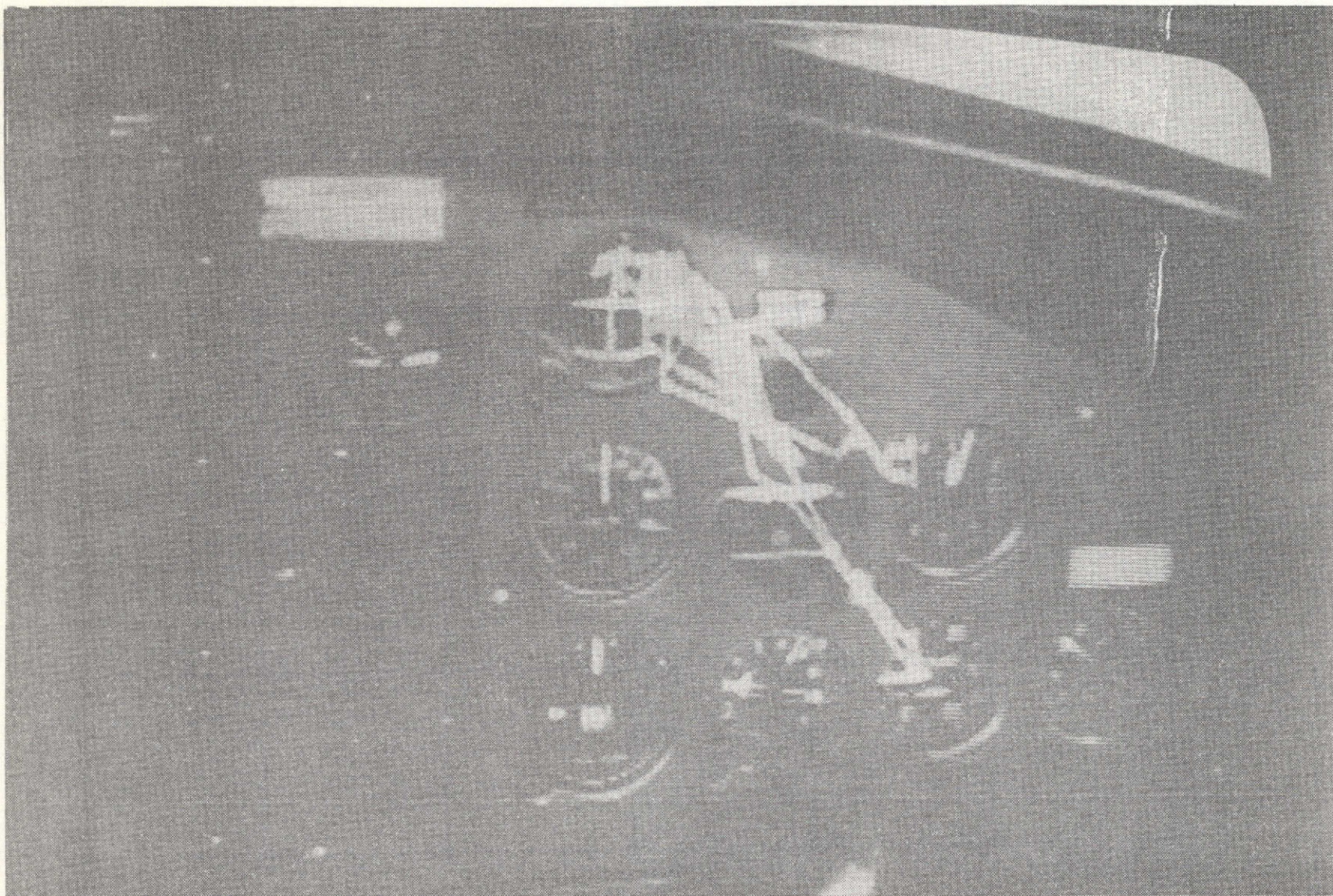


Figure 7. - Example of pilot's scan pattern superimposed on TV picture of instruments.



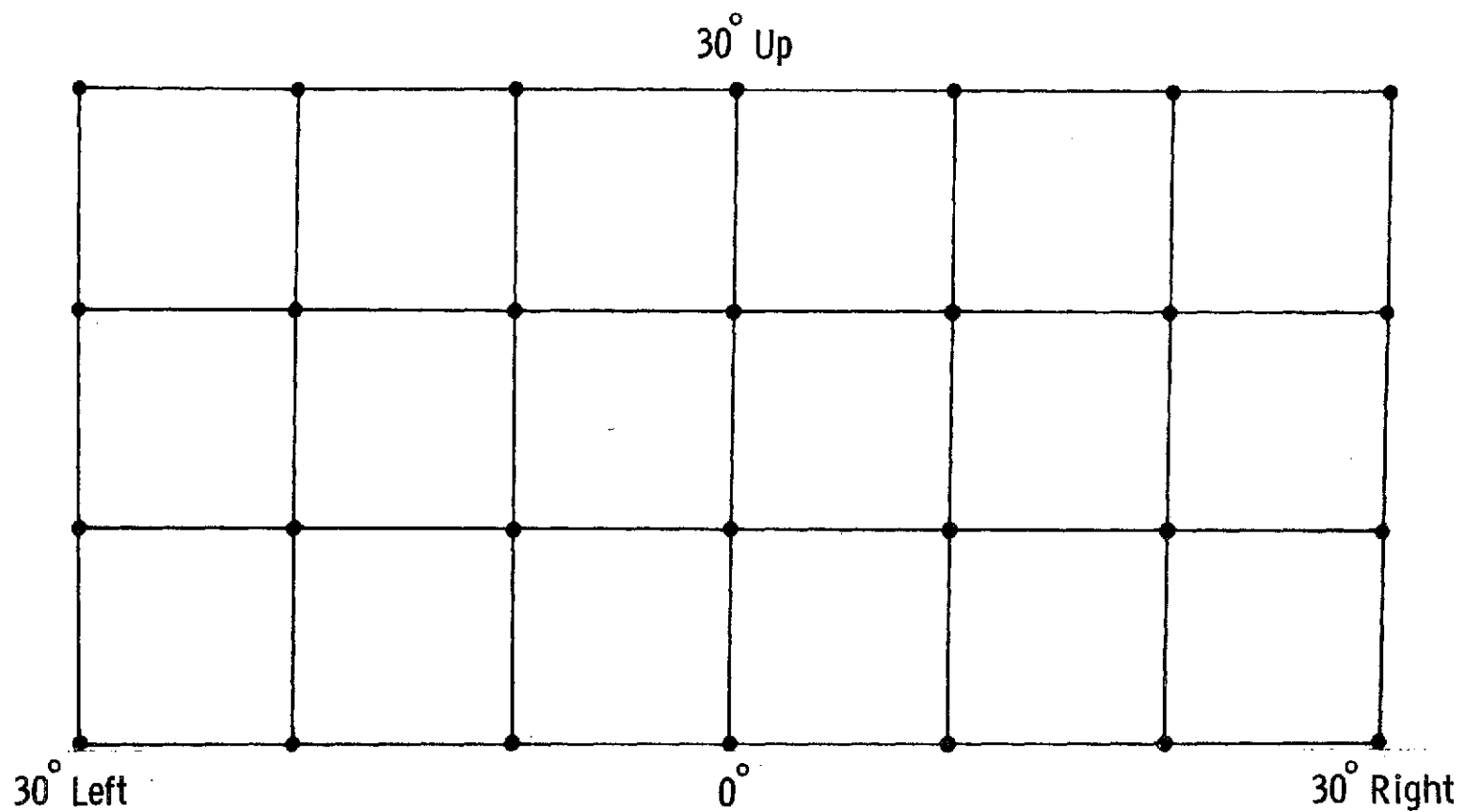


Figure 8. - Coordinates of array of nominal fixation points.

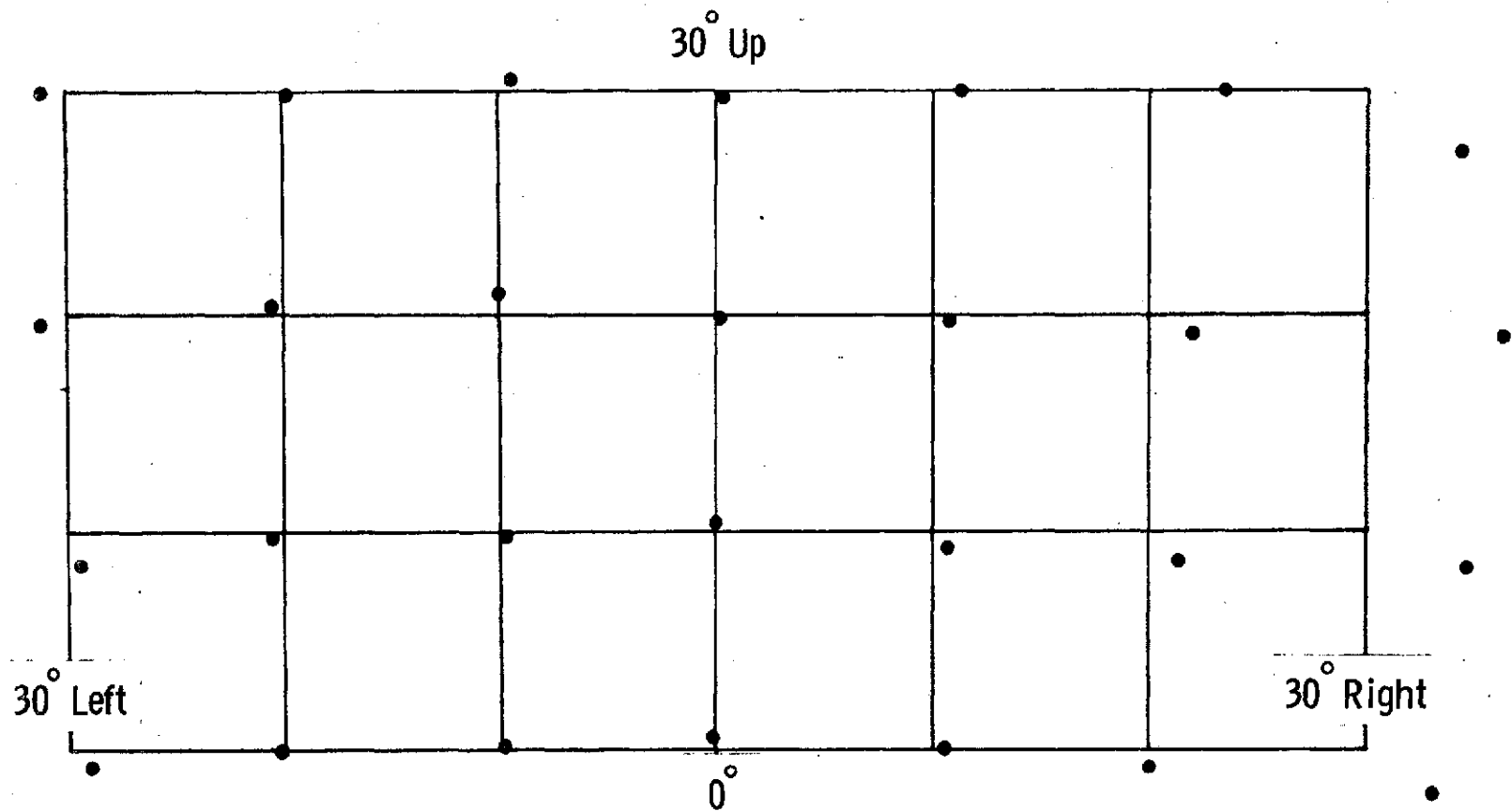


Figure 9. - Coordinates of typical uncorrected fixation-point values as measured by oculometer.

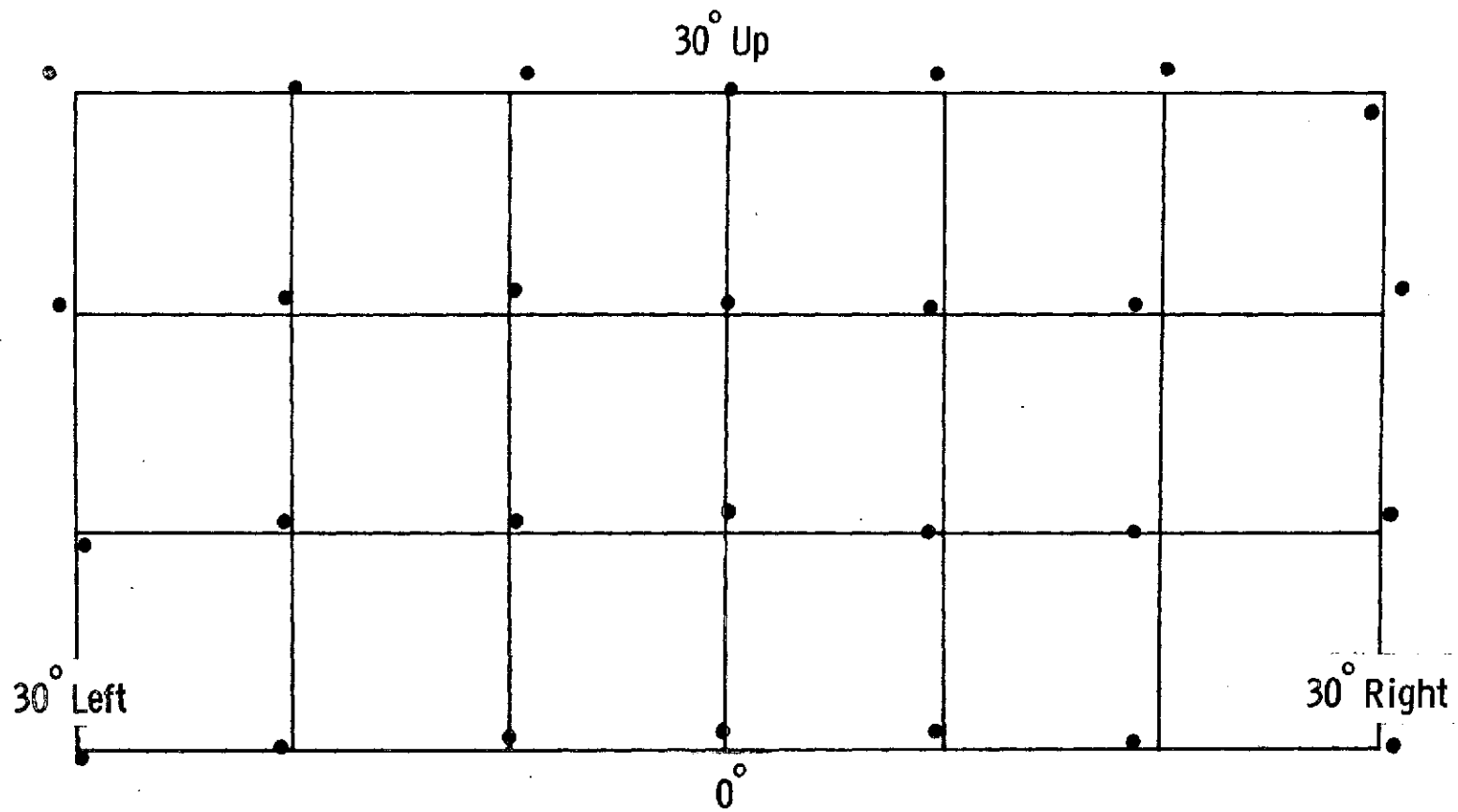


Figure 10. - Coordinates of measured fixation points after linearization.



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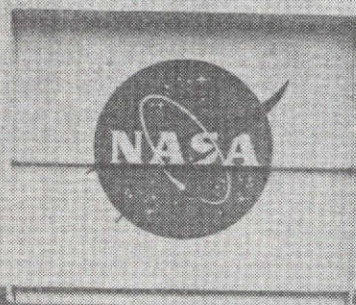


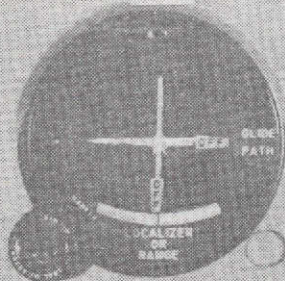
Figure 11. - Test airplane.



**CAUTION**  
MAX CONTINUOUS SINGLE GEN  
LOAD 1 KVA 115V AMP WITH  
SELECT SWITCH AT GEN

RADIO CALL  
NASA-508

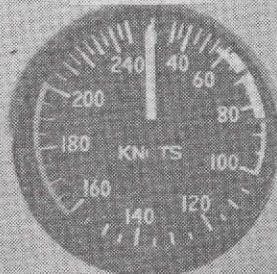
ILS



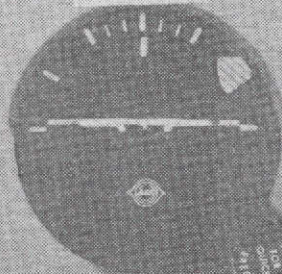
RADIO CALL  
N508NA



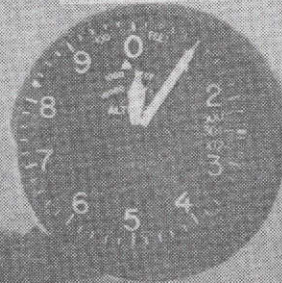
Airspeed



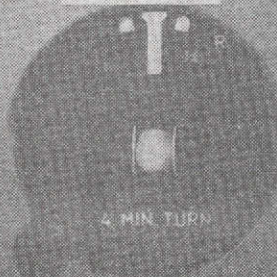
Attitude



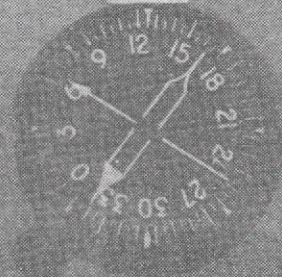
Altimeter



Turn/Slip



RMI



Vertical speed

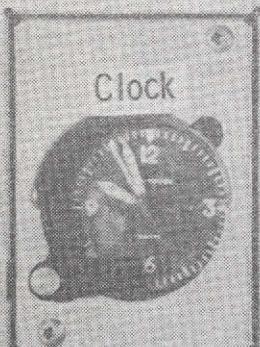
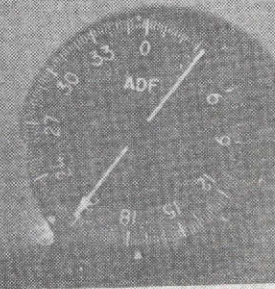
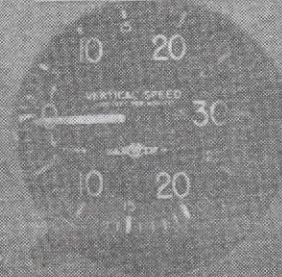


Figure 12. - The flight instruments on the co-pilot's panel.



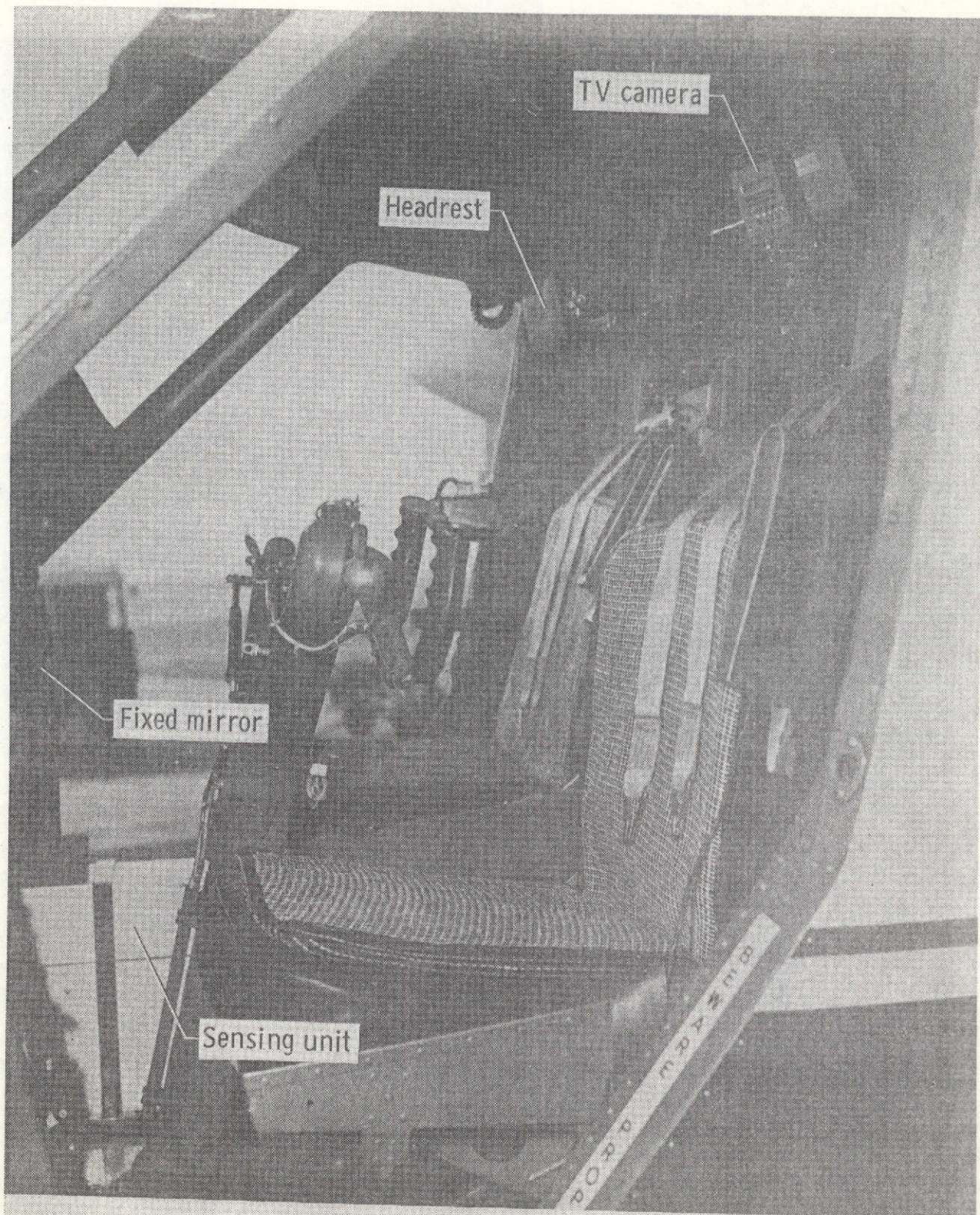


Figure 13.- Cockpit equipment added for oculometer flight tests.

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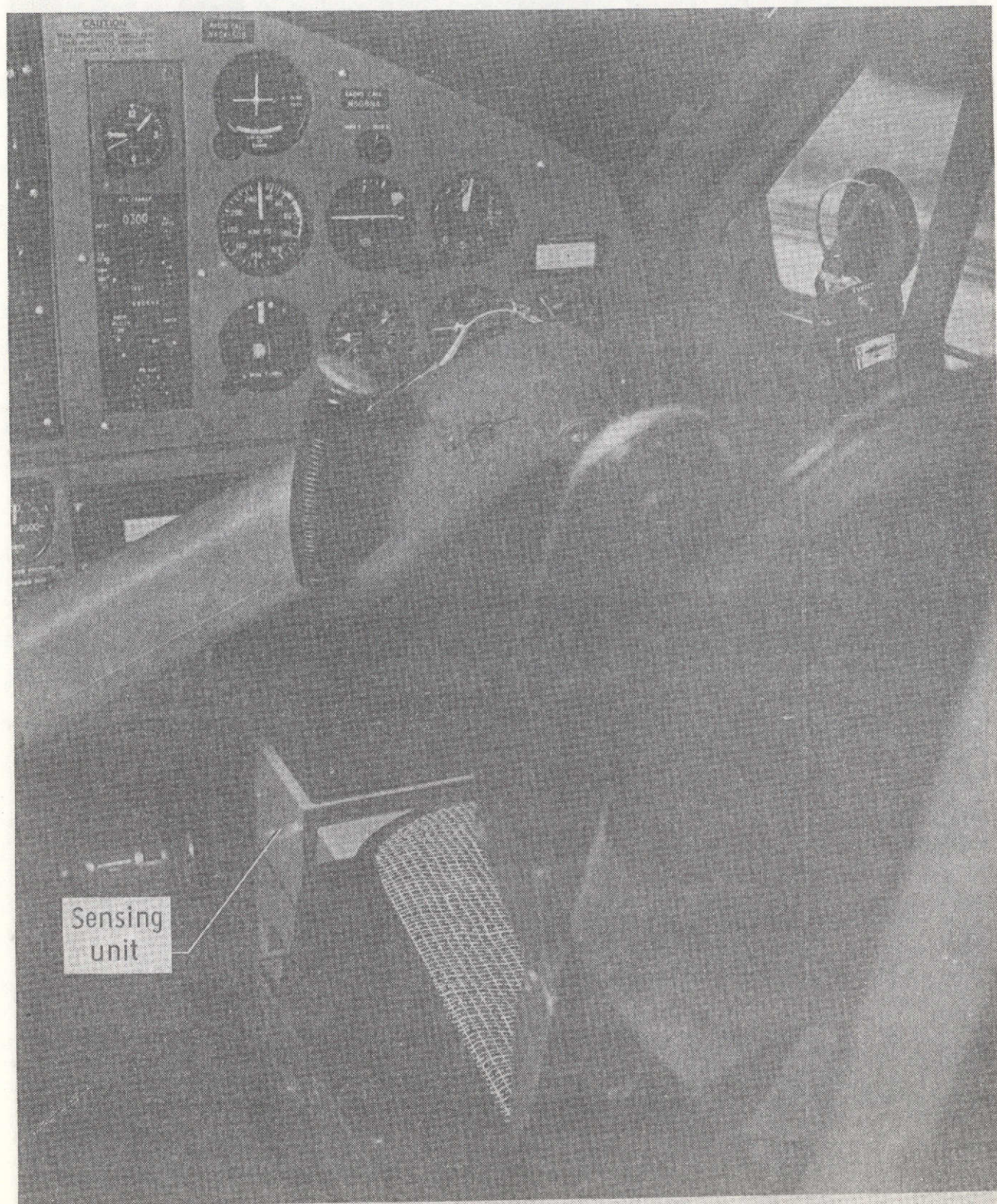


Figure 14. - View of co-pilot instrument panel from the location of the TV camera.



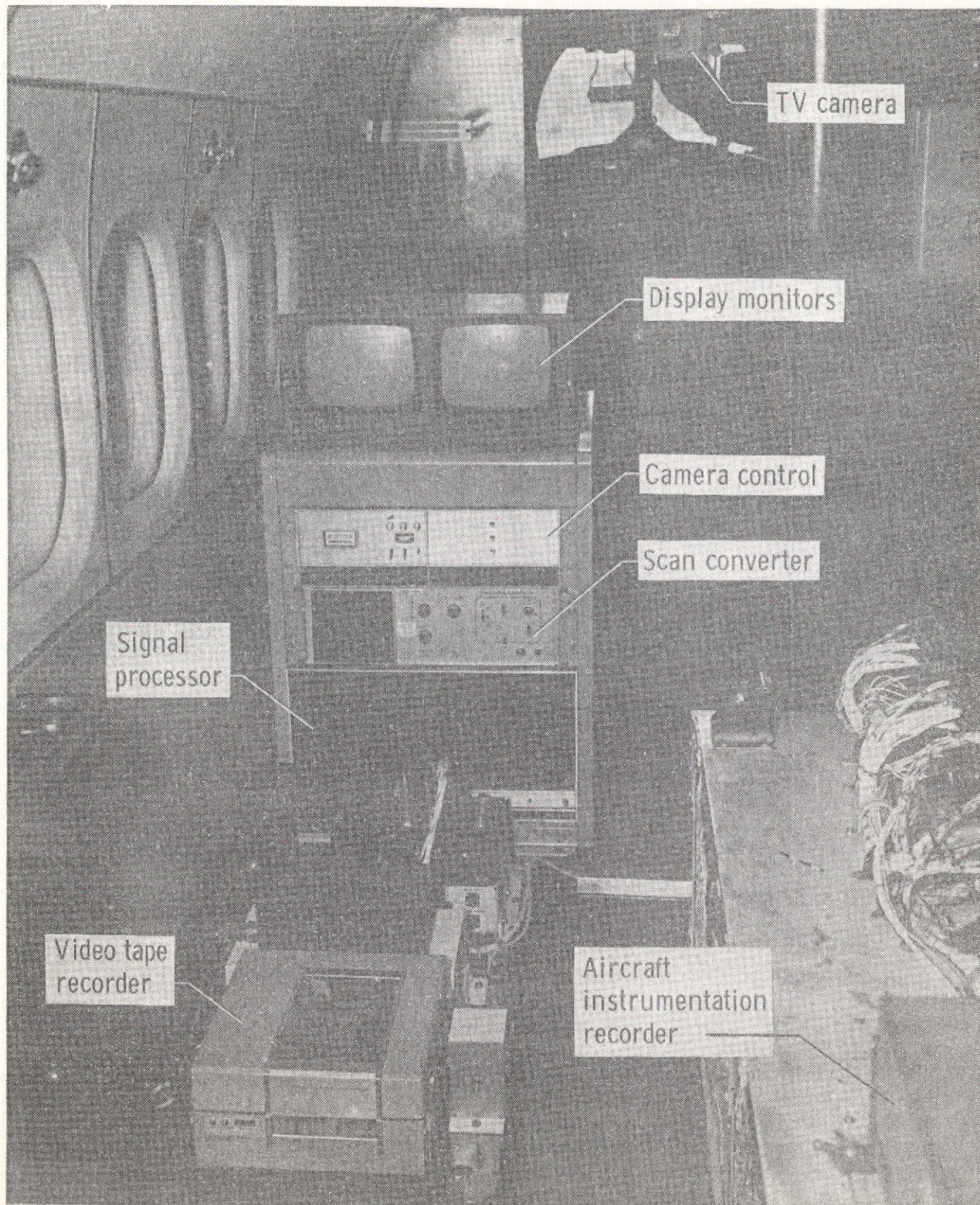


Figure 15.- Oculometer components located in passenger compartment.